BACKWARD COMPATIBLE MULTI-CARRIER TRANSMISSION SYSTEM

FIELD OF THE INVENTION

The invention generally relates to digital transmissions. It particularly relates to a new transmission system using a new modulation scheme for transmitting additional information signals over a transmission medium, which is backward compatible with a

5   former transmission system using a former modulation scheme to transmit former information signals over the same transmission medium.

The invention applies to digital transmission systems, and particularly to broadcasting systems for digital television according to the DVB-T (Digital Video Broadcasting - Terrestrial) recommendation.

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BACKGROUND OF THE INVENTION

The International patent application number PCT/IB/ 03/01544 filed on the 11th of April, 2003 with a priority date on 30, April 2002 by Koninklijke Philips Electronics describes a new transmission system of the type mentioned in the opening paragraph. It

15   enables a receiver of the former system to receive signals transmitted by the new transmission system. A drawback of this system is that the new modulation scheme adds noise to the signals received by the receivers of the former transmission system, which may disturb the receivers.

20 ## OBJECT AND SUMMARY OF THE INVENTION

It is an object of the invention to provide an improved transmission system, which allows transmitting additional information over a transmission signal of a former transmission system, which is backward compatible with the former transmission system and which yields a better quality.

25   This is achieved by a multi-carrier transmission system for transmitting information signals over a set of carriers, the set of carriers comprising a sub-set of carriers, denoted sub-carriers, each sub-carrier being modulated according to a first modulation comprising complex symbols of a first constellation, the real parts of which being proportional to a combination of the real parts of complex symbols of a second constellation,

which convey additional information signals, with the real parts of complex symbols of a third constellation, which convey parameter signaling signals, the complex parts of the symbols of the first modulation being proportional to a combination of the complex parts of the symbols of the second constellation.

5   According to the invention, the new-built transmission signals convey the former information signals over a main set of carriers and the additional information signals are embedded into parameter signaling signals, which are transmitted separately from the former information signals over a sub-set of the main set of carriers. The new-built transmission signals are transmitted with a (first) modulation, which is a predetermined

10   combination of an (second) over-modulation destined to modulate the additional information signals with a known (third) modulation, which is used to modulate parameter signaling signals. Reception and demodulation of the new-built transmission signals by the receivers of the former transmission system is rendered possible because the (second) over-modulation is added over the (third) modulation of the sub-carriers without disturbing the demodulation of

15   the latter (third) modulation by the receivers of the former system. A receiver of the former system can then receive and demodulate the former information signals and the parameter signaling signals transmitted by the new system as they did with the former system without having any knowledge of the additional information signals, which are embedded in the new built transmission signals.

20   According to a preferred embodiment of the invention, a new transmission system is provided wherein said third (TPS) modulation is of the type of the Differential Binary Phase Shift Keying (DBPSK) modulation whereby the transmitted bit is determined by the change of the transmitted symbol of the differential modulation, and wherein the symbols of the second (over) modulation are predetermined so that any couple of symbols in

25   the second constellation makes an angle, which is smaller than 90 degrees. This advantageously allows that the receivers of the former transmission system are not disturbed by the reception of signals of the new transmission system because the symbols of the second modulation are predetermined so that they don't disturb the demodulation of the former transmission signals.

30   A transmission device, a reception device, a transmission method, a computer program product and a transmission signal are also described according to the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention and additional features, which may be optionally used to implement the invention, are apparent from and will be elucidated with reference to the drawings described hereinafter, wherein which :

5 - Fig. 1 is a schematic block diagram illustrating a transmission chain according to the DVB-T transmission system,

- Fig. 2 is a schematic diagram illustrating the mapping of the differential modulation of sub-carriers of the DVB-T transmission system,

- Fig. 3 is a schematic diagram illustrating possible locations for the points of a

10 constellation for an over-modulation according to a preferred embodiment of the invention,

- Fig. 4A to Fig. 4C are schematic diagrams illustrating three alternative constellations, denoted A, B and C, respectively, according to the preferred embodiment of the invention,

15 - Fig. 5 is a schematic diagram illustrating the building of a new transmission signal according to the alternative B of the preferred embodiment,

- Fig. 6 is a schematic block diagram illustrating a transmission device according to the preferred embodiment of the invention,

- Fig. 7 is a curve illustrating the behavior of the new transmission signal for each over

20 modulations A B and C compared with the behavior of the current transmission signal with respect to the bit error rate BER and the signal to noise ratio SNR according to the preferred embodiment of the invention,

- Fig. 8 is a schematic diagram illustrating a method of de-mapping the received signals modulated according to the over modulation A,

25 - Fig. 9A to Fig. 9C are schematic diagrams illustrating a method of de-mapping the received signals modulated according to the over modulation B,

- Fig. 10A to Fig. 10C are schematic diagrams illustrating a method of de-mapping the received signals modulated according to the over modulation C.

30 DETAILED DESCRIPTION OF THE DRAWINGS

The following remarks relate to reference signs. Like letter references in different Figures designate like entities.

Fig. 1 is a functional block diagram representing the transmission chain of a DVB-T system within which the invention can be used. In all the description, the DVB-T

system is used as an example but the invention applies to any other digital transmission system. The transmission chain in plain lines comprises :

- an MPEG-2 source 10 for transmitting digital data (transport stream),
- a channel coding and modulation block 11,
5   - an OFDM frame adaptation block 12,
- and OFDM and guard interval insertion block 13 to transform the signal from the frequency domain into the time domain,
- a front end block 14 for performing digital to analog conversion and power transmission to the antenna 15 and
10   - a pilot and TPS signals blocks 16 for inserting the pilot and TPS carriers into the main DVB-T stream.

Within the DVB-T standard, 2 modes of operation are defined. The "2K mode" is suitable for single transmitter operation and for small SFN (Single Frequency Network) networks with limited transmission distances. The "8K mode" is suitable both for 15 single transmitter operation and for small and large SFN networks.

The DVB-T system uses OFDM (Orthogonal Frequency Division Multiplex) transmission. All data carriers in one OFDM frame are modulated using either QPSK, 16-QAM, 64-QAM, or non-uniform 64-QAM constellations. The constellations and the details of the Gray mapping applied to them are illustrated in the figure 9, paragraph 4.3.5 of the 20 ETSI EN 300 744 recommendation, the whole cited recommendation being incorporated herein by reference.

The transmitted signal is organized in frames. Each frame consists of 68 OFDM symbols. Each symbol is constituted by a set of K = 6817 carriers in the 8K mode and K=1705 carriers in the 2K mode. In addition to the transmitted data, an OFDM frame 25 contains pilot carriers and TPS (Transmission Parameter Signaling) carriers. The pilots can be used for frame synchronization, frequency synchronization, channel estimation, transmission mode identification. The pilots are modulated according to a reference sequence corresponding to their respective carrier index. This reference sequence also governs the starting phase of the TPS information.

30   The TPS carriers are used for the purpose of signaling parameters related to the transmission chain, that is, to channel coding and modulation. The TPS is transmitted in parallel on 17 TPS carriers for the 2K mode and on 68 TPS carriers for the 8K mode. Every TPS carrier in the same symbol conveys the same differentially encoded information bit. The TPS is defined over 68 consecutive OFDM symbols, referred to as one OFDM frame. Each

OFDM symbol conveys one TPS bit. Each TPS block (corresponding to one OFDM frame) contains 68 bits defined as follows : 1 initialization bit, 16 synchronization bits, 37 information bits and 14 redundancy bits for error protection. Of the 37 information bits, 31 are used at present and 6 are reserved for future use, and should be set to zero. The reference

5   sequence corresponding to the TPS carriers of the first symbol of each OFDM frame is used to initialize the TPS modulation on each TPS carrier. Every TPS carrier is DBPSK modulated and conveys the same message. The DBPSK is initialized at the beginning of each TPS block (of 68 bits). In a DBPSK modulation, the change of sign from one symbol to the following symbol carries the information bit.

10   Fig. 2 shows the mapping of the differential DBPSK modulation of the TPS for each OFDM symbol of an OFDM carrier. The following rule applies.

   If $S_l=0$ then $Re\{C_l\} = Re\{C_{l-1}\}$; $Im\{C_l\}=0$

   If $S_l=1$ then $Re\{C_l\} = -Re\{C_{l-1}\}$; $Im\{C_l\}=0$

with l is the index of the OFDM symbol, S_l is the transmitted TPS bit and C_l is the complex

15   TPS symbol. The TPS symbols are represented by two points in Fig. 2, which illustrate the two-points of the DBPSK constellation.

            A preferred embodiment of the invention is described herein after for allowing to transmit a new service containing additional information within the DVB-T signal, using the TPS signal to carry this additional information without disturbing existing receivers. In

20   accordance with this embodiment, which applies to the DVB-T system, a coherent "over-modulation" (hierarchical modulation) having a constellation of points which meet predetermined criteria is added over the DBPSK symbols of the TPS on a carrier-by-carrier basis. The over-modulation contains the additional information bits corresponding to the new service. The sign of the real part of the new constellation contains the TPS signal. In order

25   not to disturb the differential demodulation of the TPS signals, the angle between any two points of the constellation must be strictly smaller than 90 degrees. This avoids the jamming of the DBPSK modulation of the TPS signals by the new service. The smaller the angle, the more limited the jamming.

            In accordance with the preferred embodiment, all TPS carriers are used for

30   transmitting the additional information signal. According to an alternative embodiment, only part of the sub-carriers is used. This includes using only carriers having the same indexes in the sub-set of carriers or using carriers whose indexes vary with time. In accordance with another embodiment, robustness of the system can be improved to the detriment of the bit rate by adding redundancy in the additional information. This is obtained by copying the

same bits over several symbols of the sub-carriers (as for the regular TPS symbols defined in the cited recommendation).

Fig. 3 shows possible locations for the points of the new constellation of the new hierarchical over modulation of the TPS signals that contain the new service. The points

5   of the constellation can be located in the sector where their arguments are smaller than 45 degrees. These sectors are indicated in white, while the unsuitable locations correspond to the hatched area.

Figs. 4A to Fig. 4C show, as examples, three preferred embodiments of possible constellations for the new modulation for carrying the TPS signals and the new

10   service. In each of Figs. 4A to Fig. 4C, the symbols of the added over-modulation are represented by the points in black and the new obtained modulation is constituted by both the points in black and the hatched ones. The sign of the real parts of the points of the new obtained modulations contain the TPS information bit. Many other constellations can be built, which meet the angle requirement as indicated in Fig. 3.

15   In Fig. 4A, a single information bit is used for carrying the new service on each TPS carrier. Each bit Y_i of the new stream, with $Y_i \in \{0, 1\}$, is carried by a point z, represented in black, of the constellation, with $z \in \{1+j.0,5, 1-j.0,5\}$. For example :

$$\text{If } z = 1+j.0,5 \text{ then } Y_i = 0$$
$$\text{If } z = 1-j.0,5 \text{ then } Y_i = 1$$

20   In Fig. 4B, a pair of information bits are used for the new service on each TPS carrier. Each pair of bits $Y0_i$, $Y1_i$ of the new stream with $Y0_i, Y1_i \in \{00, 01, 11, 10\}$, is carried by a point z, wherein $z \in \{n+jm\}$ of the constellation, with $z \in \{3+j.0, 2-j, 2+j, 1+j.0\}$. For example :

$$\text{If } z = 3+j.0 \text{ then } Y0i = 0 \text{ and } Y1i = 0$$
25   $$\text{If } z = 2-j \text{ then } Y0i = 0 \text{ and } Y1i = 1$$
$$\text{If } z = 2+j \text{ then } Y0i = 1 \text{ and } Y1i = 0$$
$$\text{If } z = 1+j.0 \text{ then } Y0i = 1 \text{ and } Y1i = 1$$

In Fig. 4C, the same principle is applied. Four bits are used for the new service on each TPS carrier. Each quartet of bits $Y0_i Y1_i Y2_i Y3_i$ of the new stream is carried by a

30   point z, wherein $z \in \{n+jm\}$ of the constellation, with $z \in \{7+j.0, 6-j, 6+j, 5+j.0, 4-j.3, 5-j.2, 3-j.2, 4-j, 4+j.3, 3+2.j, 5+j.2, 4+j, 1+j.0, 2+j, 2-j, 3+j.0\}$.

In all 3 examples, the average power of the TPS carriers must be identical to the one of the data carriers of the OFDM symbol. A regulation factor, denoted Fn, must be

applied for all types of modulations. Table 1 shows examples of the regulation factors to be
applied for each of the modulations A, B and C.

Type of modulation	Regulation factor
A	$Fn = 1/\sqrt{(5/4)}$
B	$Fn = 1/\sqrt{5}$
C	$Fn = 1/\sqrt{21}$

Table 1

Fig. 5 shows the building of the new modulation over the TPS carriers. The
sign of the real part of the points of the new obtained modulation contains the TPS
information bit. The new vector $C_{l,k}$ carried by the TPS carrier k over the OFDM symbol l, is
defined by :

$$Re\{ C_{l,k} \} = Re\{ Stps_{l,k} \}.Re\{ Snew_i \}.Fn$$
$$Im\{ C_{l,k} \} = Im\{ Snew_i \}.Fn$$

with:

- Stps$_{l,k}$ is the complex symbol of the DPSK modulated TPS stream with
  $Stps_{l,k} \in \{1+j.0, -1+j.0\}$,
- Snew$_i$ is the complex symbol of the new stream, modulated with any of the A, B
  or C over modulations with $Re\{ Snew_i \} > 0$,
- Fn is the regulation factor.

Fig. 6 is a block diagram of a modified DVB-T transmission chain according
to the invention. It shows how the new TPS stream is inserted into the DVB-T signal. In
addition to the blocks of Fig. 1, it comprises :

- a new service source block 61 for providing the additional information data,
- an energy dispersal block 62 for mixing the information data with a random sequence,
- a coder block 63 and a mapper 64 for encoding and modulating the data to be
  transmitted in accordance with one of the suitable over modulations,
- a multiplier block 65 for multiplying the over modulated data containing the new
  service with the TPS and pilot signals before inserting the new stream into the DVB-T
  stream.

The number of bits that can be carried by this new modulation depends on the
required liability of the new service. Table 2 below shows the rate (not encoded) of the new
stream with respect to the chosen modulation.

Kbits/sec	#bits carried by the over modulation				
	1 A	2 B	3	4 C	5
8K or 2K ¼	61	121	182	243	304
8K or 2K 1/8	67	135	202	270	337
8K or 2K 1/16	71	143	214	286	357
8K or 2K 1/32	74	147	221	294	368

Table 2

Table 2 below shows that it is thus possible to add at least 61Kbits over the more liable DVB-T mode and 368Kbits over the least liable mode. This rate can be raised or diminished to the detriment of the homogeneity of the range of the main DVB-T stream. An error correction code can also be used to improve liability to the detriment of the rate.

This does not disturb the DVB-T reception. Only the demodulators that need it will be able to decode the new service. The over modulation does not disturb or affect the pilot carriers. Neither does it disturb or affect the data carriers of the DVB-T signal. The payload is thus not affected.

The DBPSK decoding is only slightly affected because the over modulation does not change its sign. The binary error probability Pb of the DBPSK is known. It is :

$$Pb = 1/2 \ e^{-SNR}$$

where :

- Pb is the bit error rate and

- SNR is the signal to noise ratio that measures the level of white Gaussian noise.

In the case of the TPS signal of the DVB-T recommendation, each bit is repeated 17 times in the 2K mode and 68 times in the 8K mode. The 2K mode being the less robust, only the immunity of this mode needs to be checked. It amounts to :

$$Pb_{TPS-2K} = \frac{1}{2} e^{-17.SNR}$$

The rate of the TPS signal is equal to the rate of the OFDM symbols (1 bit by OFDM symbol), which sets the maximum rate for the 2K mode with a gard interval 1/32 to :

$$TPSbit\_rate_{2K-1/32} = \frac{1}{Ts_{2K-1/32}} = 231 \mu s^{-1} = 4329 bits/s$$

where Ts is the OFDM symbol time of table 5 of the cited recommendation.

To compare the level of noise needed to be able to properly decode the TPS signals with the one necessary for a good image quality, the QEF (quasi error free) quality

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criteria can be used, which corresponds to less than one error per hour. For example, in the table A.1 of the cited recommendation, the maximum SNR for the QEF in the more robust mode is 3.1 dB. The acceptable error rate on the TPS for QEF is then. :

$$Pb_{QEF} = \frac{1}{4329*3600} = 6.41 \cdot 10^{-8}$$

$$SNR_{TPS\_2K\_QEF} = 10 \cdot \log\left(\frac{\ln(2 \cdot 6.41 \cdot 10^{-8})}{-17}\right) = -0.3dB$$

5   It is to be noticed that the level of SNR of the TPS is 3,4dB higher in the more robust mode of the DVB-T payload stream. This rate is very pessimistic because in general, the decoders only use the TPS during a very short period corresponding to the lock (acquisition) time.

Fig. 7 shows the behavior of the new built streams for each over modulations A B and C compared with the behavior of the current TPS stream with respect to the BER

10   (vertical axis) and SNR (horizontal axis). The two limits constituted by the BER of $6{,}4 \cdot 10^{-8}$ and the SNR of 3,1 dB are indicated with bold horizontal and vertical lines, respectively. Fig. 7 shows that the over modulations can then be considered not to affect the TPS signal because for the maximum level of noise, which is tolerated by the MPEG-2 stream, the BER on the TPS stream remains below the QEF.

15   Depending on the chosen new over modulation, coherent demodulation can be realized in a similar way as for the data of the main DVB stream. This is illustrated in Fig. 8 to Fig.10.

Fig. 8 illustrates an example of a method for de-mapping the type A over modulation. The following rule applies, R being the complex symbol received demodulated,

20   represented in Fig. 8 by a point of a constellation, and Y_1 being the binary symbol {0, 1} to generate :

if $\text{Im}\{R\}>0$ then $Y_1=0$ else $Y_1=1$.

Fig. 9A to Fig. 9C show an example of a method for de-mapping the type B over modulation for a given carrier of symbol l, wherein R_l is the complex Symbol received

25   demodulated and $Y0_l$, $Y1_l$ is the pair to generate among 4 ($2^2=4$) possible pairs {00, 01, 11, 10}. It is possible to match the over modulation B with the classical QPSK modulation of the DVB-T data as described in table 9a of the cited recommendation and to demodulate the new TPS stream the same way as for the QPSK demodulation of the DVB-T stream. Same hardware can then be used. To this end, the symbol S_l received and demodulated can be

30   transformed by translation and rotation into the symbol $S_{l'}$:

$$Re\{S_{l'}\} = |Re\{ S_l\}|- 2 - Im\{ S_l\}$$

$$Im\{S_{l'}\} = |Re\{ S_l\}|- 2 + Im\{ S_l\}$$

-if $Re\{S_{l'}\}>0$ then $Y0_l=0$ else $Y0_l=1$.

-if $Im\{S_{l'}\}>0$ then $Y1_l=0$ else $Y1_l=1$.

Fig. 10A to Fig. 10C show an example of a method for de-mapping the type C over modulation. The same principle as for modulation B is applied wherein S_l is the complex Symbol received demodulated, $S_{l'}$ is the symbol obtained by translation and rotation of symbol S_l and $Y0_l$, $Y1_l$, $Y2_l$ and $Y3_l$ is the quartet to generate among 16 ($2^4=16$) possible quartets {0000, 0001, 0010, 0010, 0111, 0101, 0110, 0100, 1101, 0111, 1100, 1110, 1000, 1010, 1001,1011}:

$$Re\{S_l'\} = |Re\{ S_l\}|- 4 - Im\{ S_l\}$$

$$Im\{S_l'\} = |Re\{ S_l\}|- 4 + Im\{ S_l\}$$

Then :

-if $Re\{S_l'\}>0$ then $Y0_l=0$ else $Y0_l=1$.

-if $Im\{S_l'\}>0$ then $Y1_l=0$ else $Y1_l=1$.

-if $Re\{S_l'\}>2$ then $Y2_l=0$ else $Y2_l=1$.

-if $Im\{S_l'\}>2$ then $Y3_l=0$ else $Y3_l=1$.

Then the new (TPS) sub-stream can be demodulated like a 16-QAM DVB-T stream.